Alive and Kicking

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Alive and Kicking: Baby Steps in Robotics

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Both the concept of evolution and our understanding of it have themselves evolved over many years. In the 19th century, the notion of evolution gained prominence as an a posteriori explanation of the development of life on Earth. In the 20th century, the principles of evolution were applied in computers, to evolve solutions to optimization and design problems. In this new field – Evolutionary Computing – the objects undergoing evolution are digital entities. In the 21st century, the field of Evolutionary Computing is entering a new phase, with the development of algorithms capable of applying evolutionary processes to physical entities. These physical objects fall into two categories, *inanimate* entities (e.g. coffee mugs) and *animate* entities (e.g. robots). The evolution of the latter is much more interesting than that of the former, because we can evaluate what they do, not just what they are. Our aim was to contribute to the next step forward, which involves transferring evolution from simulations to real-world physical entities.

The entities that evolved in the system presented here are *robot organisms* – in our case, modular robots. These robots were assembled from functional components. The main research goal was to demonstrate the feasibility of the Evolution of Things, and to investigate its constituent elements. The main constituents required for the Evolution of Things are *Birth*, *Lifetime Learning*, and *Procreation*. Birth is the process of assembling and delivering a new robot entity. In the case of a new robot, Lifetime Learning is the process in which the robot learns how to control its body and how to interact with the environment. Procreation is the process of mate selection and reproduction within a population of robots. The Lifetime Learning process proved to be the most challenging of these constituents.

We investigated constituents of relevance to the evolution of modular robots. The research question in this context was: 'How could a system like this be developed and what factors primarily influence it?'

The most significant contribution of this thesis is a proof-of-concept study demonstrating that real, physical robots can reproduce. We presented a simplified version of the Triangle of Life concept – a system in which robots can interact, learn and reproduce. An initial population of two robots was created. Next, a complete life cycle was performed, resulting in a new robot that was parented by the first two. Each individual step in the process was made as simple as possible. Nevertheless, the system as a whole validates the underlying concepts and provides a generic workflow for the creation of more complex incarnations.

We also explored a new type of controller that, uniquely, is assembled from two parts: a body-specific part (Coupled Differential CPG) and body-agnostic part (CPPN). The structure of the CD-CPG is derived from the robot's own body structure. It regulates the robot's behaviour based on weighted values for its connections. The structure of the CPPN determines the weighted values of CD-CPG connections, and is optimized using the HyperNEAT algorithm. The use of a dual-nature controller confers a number of advantages. Firstly, it facilitates the implementation of Lamarckian evolution in an artificial system. Secondly, it makes it possible to compare the influence of bodies and brains on locomotion performance. Lastly, it makes social learning (i.e. knowledge transfer) possible.

Finally, we compared Darwinian and Lamarckian evolutionary setups in which both the brains and bodies of robots are evolvable. Such systems need to include a learning period immediately after 'birth', to produce a controller that fits the newly created body. This showed that inheriting 'experienced' parental controllers speeds up infant learning. Thus, the use of a Lamarckian set-up is advisable. We can draw further conclusions, based on the evolved morphologies. Remarkably, even though the difference between the Darwinian and Lamarckian versions only affected the controllers, it also had an impact on morphology.